Temporal variations in reptile assemblages in the Goldfields of Western Australia

S A Thompson[1] & G G Thompson[2*]

[1]ATA Environmental, Dilhorn House, 2 Bulwer Street, Perth, Western Australia, 6000,
✉ scott.thompson@ataenvironmental.com.au

[2]Centre for Ecosystem Management, Edith Cowan University, Joondalup Dr, Joondalup, WA, 6027,
✉ g.thompson@ecu.edu.au
* corresponding author.

(Manuscript received November 2004; accepted March 2005)

Abstract

We report significant variation in reptile pit-trapping results for eleven survey periods over two and half years for nine sites in the Goldfields region of Western Australia. We collected a total of 51 species and 2868 individual reptiles from a surveying effort of 33264 pit-trap days. Year-to-year variation in relative abundances for particular species was greater than elsewhere reported as being the result of stochastic events such as fires. Seasonal variation in catch rates suggest that to adequately survey an area, pit-trapping programs need to be undertaken in more than one season. This has significant (financial) consequences for mining companies and other industries that employ consultants to undertake terrestrial fauna surveys to describe that component of the biodiversity for an area. Environmental protection agencies need to adjust their guidelines for terrestrial faunal surveys to adequately describe the biodiversity of an area. Our data indicate that before researchers can claim that year-to-year variation in reptile assemblages are due to stochastic events they must account for 'normal' year-to-year variations.

Keywords: reptile assemblage, fauna surveys, temporal variations, seasons, EIA, pit-trapping, Ora Banda

Introduction

Environmental consultants typically survey a site once and draw conclusions about the vertebrate faunal assemblage. For example, Fraser *et al.* (2003) having reviewed the adequacy of 15 terrestrial faunal surveys in the Goldfields region of Western Australia (WA) for the purposes of preparing an environmental impact assessment (EIA), reported that only three environmental consultants surveyed in two seasons, seven surveyed on one occasion and the remaining five did not explicitly indicate when they surveyed. EIAs are an important component in the planning and approval process for the development of a mine site or any other type of disturbance to the natural environment (Environmental Protection Authority 2002). Outcomes from terrestrial faunal surveys undertaken for purposes of preparing an EIA are the basis of decisions by government regulatory authorities on potential impacts of disturbance. Fauna survey data can also be used to monitor and judge the extent to which rehabilitation programs are able to recreate near-natural, self-sustaining, functional ecosystems at the conclusion of mining (Thompson 2004). Is it then reasonable for environmental consultants to survey an area in one season or even in a couple of seasons in a single year and presume to understand the vertebrate faunal assemblage for that area for purposes of preparing an EIA?

Some field ecologists have surveyed an area a couple of times and have drawn conclusions about the impact of stochastic events (e.g. rainfall, fire) on vertebrate assemblages, without reporting 'normal' seasonal and year-to-year variations for that assemblage. For example, James (1994) and Pianka (1996) have attributed changes in reptile assemblages to the impact of heavy rainfall or fires but have not been able to demonstrate the variations in relative abundance are greater than normal year-to-year variation due to local environmental and geophysical conditions that are within the normal range for that area. Cowan & How (2004) adequately demonstrated significant seasonal and long-term variation in small vertebrate assemblages in the eastern Goldfields and questioned the ability of short-term surveys to describe vertebrate assemblages for EIA.

The Goldfields region of WA has been extensively mined for over a century and terrestrial fauna surveys undertaken for purposes of preparing EIA's are a relatively common occurrence in this region. Reptile assemblages in this and other mining areas of WA are generally estimated based on trapping (pit-traps and Elliott traps) and hand searching programs (Fraser *et al.* 2003). Before we can make judgements about the impact of stochastic events (e.g. fire, rainfall) on reptile assemblages in arid and semi-arid Australia, it is important to understand natural seasonal and year-to-year variations, the impact of heavy rainfall events and fires, and the sessional processes after these stochastic events. Our objective is to report variations in reptile assemblages from season-to-season, and year-to-year when the survey effort remained constant for a semi-arid, Eucalypt-Casuarina-Mulga woodland in the Goldfields region of WA in the context of detailed

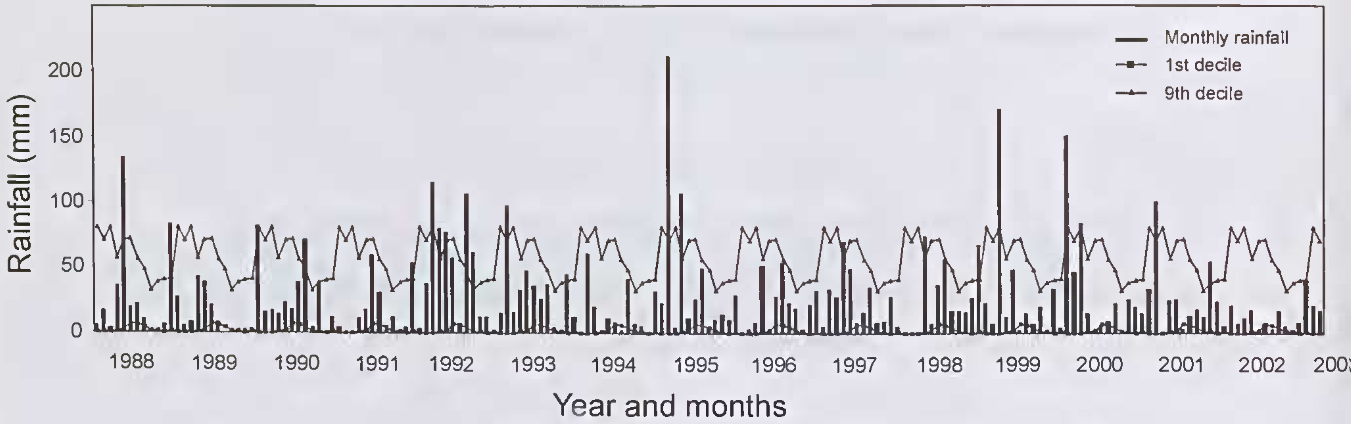

Figure 1. Cumulative monthly rainfall at Placer Dome Asia Pacific, Kalgoorlie West Operations from 1988 until 2003.

information on local rainfall, a reported major determinant of reptile abundance (Bradshaw *et al.* 1991; James 1991, 1994; Saint Girons *et al.* 1992; Spiller & Schoener 1995; Dickman *et al.* 1999).

'Normal' in the context of rainfall is difficult to define in the goldfields region. Variability is demonstrated by the histogram (Fig 1) of cumulative monthly rainfall for Placer Dome Asia Pacific, Kalgoorlie West Operations (the closest weather station to our study sites) showing the 1st and 9th deciles for rainfall at the Kalgoorlie-Boulder Airport (calculated from 1939 to 2001), which is about 50km to the south.

Methods

Study sites

We have used data collected over a two and a half year period for nine relatively undisturbed sites (Gimlet, Palace, Rose, Wendy Gully, Salmon Gums, Spinifex, Davyhurst, Security and Crossroads) in the gold mining region of Ora Banda (30° 27' S, 121° 4' E; approximately 50 km north of Kalgoorlie; Fig 2), WA. Ora Banda lies on Archaen granites that underlie lateritic gravel soils. The vegetation was heterogenous, ranging from Eucalypt-Casuarina-Mulga woodlands interspersed with *Acacia*, to sparsely distributed spinifex (*Triodia* spp.) and shrubs (*Acacia* spp.) to dense shrubs (*Acacia* spp., *Atriplex* spp., *Allocasuarina* spp.). Each of the nine sites was chosen because they represented a different vegetation type but were typical for the area (Mattiske Consulting Pty Ltd 1995). There was no indication of fires in the records of the mining companies that had control over the tenements on which the study sites were located or fire scars on the vegetation to suggest any of the sites had been recently burnt. Because of the sparseness of the vegetation and lack of undergrowth major fires in this area are rare, but when they occur they are generally remembered by people that live and work in the area.

Weather information

Minimum and maximum ambient temperature, and cloud cover data, for each survey period were collected from the Bureau of Meteorology in Kalgoorlie (http://www.bom.gov.au/climate/averages/tables/cw_012038.shtml), the closest government weather station. Rainfall data came from Placer Dome Asia Pacific, Kalgoorlie West Operations, which was within 25 km of all study sites. Rainfall, particularly summer thunderstorms, can be localised and the mine site data better represents rainfall at our sites than that from the Bureau of Meteorology in Kalgoorlie, which is further away. The Kalgoorlie Bureau of Meteorology has kept records for the Kalgoorlie-Boulder site since 1939 and Placer Dome Asia Pacific, Kalgoorlie West Operations has kept records since 1988. Means and percentiles were calculated for these periods.

Data collection strategies

All sites were pit-trapped on eleven occasions between September 2000 and January 2003 (September and December in 2000; January, April, June, September and December in 2001; January, April and June in 2002; and January 2003) using alternating 20 L PVC buckets and 150 mm PVC pipes (600 mm deep) joined by 250 mm high x 30 m long fly-wire drift fences. Each site had eight rows of six pit-traps (Fig 2). All pit-traps were dug in during June-July 2000 to minimise potential digging-in effects on reptile capture rates. During each surveying period, each pit-trap was opened for seven days and pit-traps were cleared daily. In September, December and January survey periods, pit-traps were divided into two groups and surveyed in successive weeks. Mean minimum and maximum ambient temperatures for these two seven day periods were not significantly different for all survey periods, so weather data were combined for these periods and means are reported for each surveying period. Each reptile captured was sexed (where possible), weighed and measured. Most reptiles were identified before immediately being released adjacent to its point of capture; a few were vouchered with the Western Australian Museum (WAM). Recaptures have been included in the analysis. We report 33264 pit-trap days of data.

We appreciate that there was approximately three months gap between the September-December, January-April, April-June and June-September surveying periods and a much shorter period between December-January surveying. As a consequence, it is probable that the December and January catches would be more similar than the other surveying periods because they are closer together. Most reptile surveys are undertaken in the

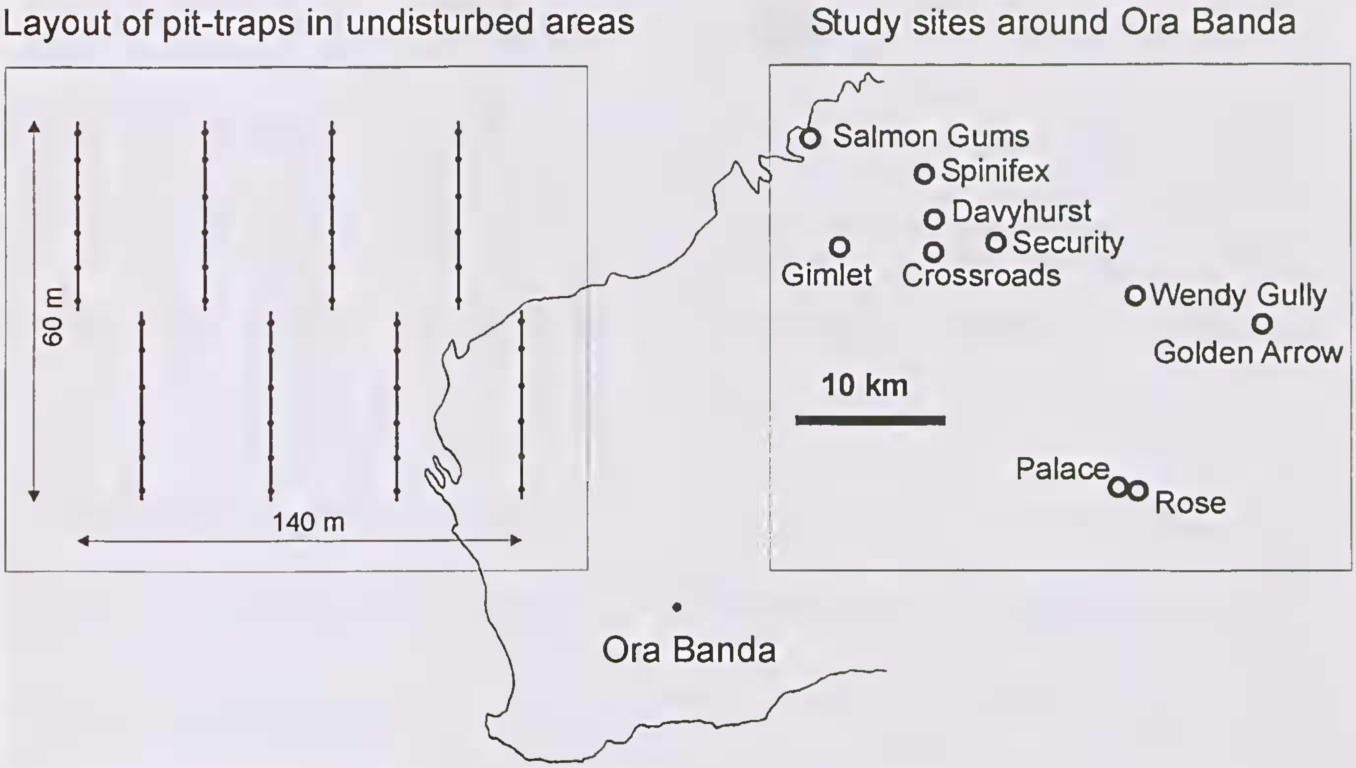

Figure 2. Location of Ora Banda, nine study sites and pit-trap layout.

warmer months, but there is limited commentary in the literature on whether there are differences in the composition of pit-trapping catches within this period (however, see Cowan & How 2004). We chose to survey in both December and January to assess the similarity of catches within this period.

Data analysis

We examined reptile assemblage structure for the Ora Banda region by combining seven days of pit-trap data for each of the nine sites and then compared reptile assemblages for each of the eleven surveying periods (3024 pit-trap days for each period).

We report the total number of species caught in the surveying period, diversity using log-series (a), Shannon's (H) and Simpson's (D) diversity indices (using Pisces Conservation Ltd 2002, Species Diversity and Richness II software). Log-series diversity has good discriminating ability, low sensitivity to sample size and is widely used (Magurran 1988). Shannon's and Simpson's diversity indices are included as they are commonly reported and these data can be compared with other reports. We measured and report evenness (J; using Pisces Conservation Ltd 2002, Species Diversity and Richness II software) and similarity using Morisita-Horn index (using Colwell 1997, EstimateS software). Tramer's (1969) measure of evenness is widely used and the Morisita-Horn similarity index was used because it accounts for relative abundance and was recommended by Magurran (1988).

Results

Weather for the survey period

Typically, the Goldfields region of WA has hot summers and cool winters (Table 1). Rainfall episodes in winter are generally less than 20 mm and more frequent, whereas summers are characterised by many days of no rainfall and a few days of unpredictable rainfall mostly

Table 1

Rainfall (mm) and temperature (°C) statistics for Kalgoorlie-Boulder airport from 1939 to 2004

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean monthly rainfall	22.8	31.5	23.6	22.1	27.8	29.6	25.4	21.7	14.5	15.1	18.2	16.1
1st decile of monthly rainfall	0.3	0	0.4	1	2.4	6.2	5.5	4.5	0.7	0.9	0.4	1.3
Median monthly rainfall	7.1	12.5	9	14.8	21.8	21	20.8	15.9	11.2	9.4	15.3	11
9th decile of monthly rainfall	74	74.2	80.1	56.5	67.9	68.2	53.1	46.7	31.4	36.4	40.4	41.4
Lowest monthly rainfall	0	0	0	0	0	2.1	0.6	1.6	0.3	0	0	0
Highest monthly rainfall	185.9	307.8	197.0	98.6	110.2	185.7	82.6	74.0	98.3	84.4	115.4	88.6
Highest recorded daily rainfall	154.4	177.8	70	49.8	45.2	57.2	28.6	49.6	44.2	45.6	77	28.2
Mean daily maximum temperature	33.6	32	29.5	25.1	20.5	17.5	16.7	18.4	22.2	25.6	28.9	31.9
Mean daily minimum temperature	18.2	17.8	16.0	12.6	8.6	6.2	4.9	5.5	7.9	10.9	14.0	16.5

Table 2

Total number of individuals caught, total number of species caught, number and percentage of hatchlings caught for each family, diversity and evenness values for the combined nine sites around Ora Banda for each of the eleven survey periods

	Sep-00	Dec-00	Jan-01	Apr-01	Jun-01	Sep-01	Dec-01	Jan-02	Apr-02	Jun-02	Jan-03	Change Sep	Change Dec	Change Jan	Change Apr	Change Jun	Change Jan 01 to 02, 03
Agamids																	
Caimanops amphiboluroides	0	0	0	0	0	0	0	0	0	0	1	-2	-1	-7	1	0	-7, -5
Ctenophorus cristatus	0	0	4	0	0	0	0	2	0	0	0	-2	-1	-2	1	-1	-2, -10
Ctenophorus reticulatus	9	2	14	0	1	7	1	12	1	0	4	-4	2	-1	8	0	-1, -2
Ctenophorus scutulatus	3	0	3	0	1	3	1	2	2	0	0	0	1	-1	2	-1	-1, -3
Moloch horridus	5	1	2	0	0	1	3	1	8	0	0	-5	-2	0	0	0	0, 0
Pogona minor	10	5	12	2	0	8	4	5	3	0	7	0	0	-2	0	0	-2, -4
Tympanocryptis cephala	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0, 1
Geckos																	
Diplodactylus granariensis	77	44	45	9	1	37	40	47	18	1	27	-40	-4	2	9	0	2, -18
Diplodactylus mainii	61	47	49	36	0	42	46	48	20	0	52	-19	-1	-1	-16	0	-1, 3
Diplodactylus pulcher	38	64	79	28	0	32	28	63	26	0	74	-6	-36	-16	-2	0	-16, -5
Gehyra purpurascens	0	4	12	1	0	0	1	1	0	0	0	0	-3	-11	-1	0	-11, -12
Gehyra variegata	12	22	65	9	1	4	14	23	7	0	9	-8	-8	-42	-2	-1	-42, -56
Heteronotia binoei	1	11	15	4	0	2	5	3	2	0	21	1	-6	-12	-2	0	-12, 6
Oedura reticulata	0	0	4	0	0	0	0	0	0	0	1	7	-14	-23	-12	0	-23, 0
Rhynchoedura ornata	1	21	30	16	0	8	7	7	4	0	30	-13	-31	-4	1	0	-4, -20
Strophurus assimilis	25	43	24	0	0	12	12	20	1	0	4	-2	-8	1	2	0	1, -6
Underwoodisaurus milii	6	11	11	4	0	4	3	12	6	0	5	0	0	-4	0	0	-4, -3
Pygopods																	
Delma australis	3	6	3	2	0	0	0	5	0	0	1	-3	-6	2	-2	0	2, -2
Delma butleri	0	1	0	0	0	0	0	2	0	0	0	0	-1	2	0	0	2, 0
Delma fraseri	0	1	1	0	0	0	0	0	0	0	0	0	-1	-1	0	0	-1, -1
Lialis burtonis	2	0	0	0	0	1	0	0	0	0	0	-1	0	0	0	0	0, 0
Pygopus lepidopodus	0	0	1	0	0	1	0	1	0	0	0	1	0	0	0	0	0, -1
Skinks																	
Cryptoblepharus plagiocephalus	4	10	5	0	1	4	2	2	1	0	1	0	-8	-3	1	-1	-3, -4
Ctenotus atlas	13	10	23	3	0	4	4	9	1	0	3	-9	-6	-14	-2	0	-14, -20
Ctenotus schomburgkii	0	0	0	1	0	0	0	0	0	0	0	-11	-14	-2	9	0	-2, -14
Ctenotus uber	19	17	19	5	0	8	3	17	14	0	5	0	0	0	-1	0	0, 0
Cyclodomorphous m. elongatus	8	7	8	0	0	3	0	5	1	0	2	-5	-7	-3	1	0	-3, -6
Egernia depressa	19	21	29	4	0	1	1	4	3	0	8	-18	-20	-25	-1	0	-25, -21
Egernia formosa	0	4	5	0	0	1	0	1	0	0	1	1	-4	-4	0	0	-4, -4
Egernia inornata	1	1	14	4	0	3	5	14	0	0	7	0	0	4	0	0	4, 3
Egernia striata	0	0	0	0	0	0	0	4	0	0	3	0	0	2	-3	0	2, 0
Eramiascincus richardsonii	0	2	2	3	0	0	2	4	0	0	2	1	1	0	0	0	0, 0
Hemiergis i. initialis	3	2	0	0	0	4	3	0	0	0	0	2	4	0	-4	0	0, -7
Lerista muelleri	1	17	9	0	0	1	3	8	1	0	5	0	-14	-1	1	0	-1, -4
Lerista picturata	4	31	21	2	0	0	7	12	4	0	8	-4	-24	-9	2	0	-9, -13
Menetia greyii	37	8	12	15	0	6	6	3	5	0	1	-31	-2	-9	-10	0	-9, -11
Morethia butleri	8	9	4	2	0	2	6	1	3	0	4	-6	-3	-3	1	0	-3, 0
Tiliqua occipitalis	1	0	0	0	0	0	0	1	0	0	0	-1	0	1	0	0	1, 0
Tiliqua rugosa	0	1	0	0	0	2	1	0	0	0	0	2	0	0	0	0	0, 0

Varanids																	
Varanus caudolineatus	1	8	9	3	0	3	1	5	1	0	3	2	-7	-4	-2	0	-4, -6
Varanus gouldii	0	4	4	0	0	0	1	2	2	0	1	0	0	1	0	0	1, 0
Varanus tristis	0	0	0	0	0	0	0	1	0	0	0	0	-3	-2	2	0	-2, -3
Blind snakes												0	0	0	0	0	0, 0
Ramphotyphlops australis	12	1	6	0	0	1	3	6	0	0	10	-11	2	0	0	0	0, 4
Ramphotyphlops bituberculatus	1	1	1	0	0	0	0	0	0	0	0	7	-7	7	0	0	7, -8
Ramphotyphlops hamatus	6	7	11	1	0	13	0	18	1	0	3	-1	-1	-1	0	0	-1, -1
Elapids												0	0	0	0	0	0, 0
Brachyurophis semifasciata	0	9	4	0	0	0	0	4	0	0	3	0	-9	0	0	0	0, -1
Demansia psammophis	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0, 1
Parasuta monachus	4	6	2	0	0	3	4	6	3	1	1	-1	-2	4	3	1	4, -1
Pseudonaja modesta	1	1	1	0	0	0	0	0	0	0	0	-1	-1	-1	0	0	-1, -1
Simoselaps bertholdii	0	2	2	0	0	0	3	1	0	0	1	0	1	-1	0	0	-1, -1
Suta fasciata	1	0	1	0	0	0	2	1	0	0	1	-1	2	0	0	0	0, 0
# of Agamidae	32	10	35	2	2	19	9	22	14	0	12	-13	-1	-13	12	-2	-13, -23
# of Gekkonidae	221	267	334	107	2	141	156	224	84	1	223	-80	-111	-110	-23	-1	-110, -111
# of Pygopodidae	5	8	5	2	0	2	0	8	0	0	1	-3	-8	3	-2	0	3, -4
# of Scincidae	118	140	151	39	1	39	43	85	33	0	50	-79	-97	-66	-6	-1	-66, -101
# of Varanidae	1	12	13	3	0	3	2	8	3	0	4	2	-10	-5	0	0	-5, -9
# of Typhlopidae	19	9	18	1	0	14	3	24	1	0	13	-5	-6	6	0	0	6, -5
# of Elapidae	6	18	10	0	0	3	10	12	3	1	7	-3	-8	2	3	1	2, -3
Total # of individuals caught	402	464	566	154	5	221	223	383	138	2	310						
Total # of species caught	34	39	40	21	5	30	32	40	25	2	35						
# of hatchling agamids (%)	*	*	16 (45.7)	*	*	*	*	7 (31.8)	3 (21.4)	*	*						
# of hatchling geckos (%)	*	4 (1.5)	16 (4.8)	3 (2.8)	*	*	1 (0.6)	3 (1.3)	3 (3.6)	*	3 (1.3)						
# of hatchling pygopods (%)	*	*	2 (40.0)	*	*	*	*	*	*	*	*						
# of hatchling skinks (%)	5 (4.2)	8 (5.7)	9 (6.0)	7 (17.9)	*	1 (2.6)	2 (4.7)	5 (5.9)	8 (24.2)	*	3 (6.0)						
# of hatchling varanids (%)	*	*	4 (30.8)	2 (66.7)	*	*	*	*	1 (33.3)	*	*						
# of hatchling blind snakes (%)	*	*	1 (5.6)	*	*	*	1 (33.3)	*	*	*	1 (7.7)						
# of hatchling elapids (%)	1 (16.7)	*	*	*	*	*	*	*	*	1 (100.0)	*						
# of hatchling in total sample (%)	6 (1.5)	12 (2.6)	48 (8.5)	12 (7.8)	*	1 (0.5)	4 (1.8)	15 (3.9)	15 (10.9)	1 (50.0)	7 (2.3)						
Simpson's diversity index	11.21	15.87	16.24	8.71	⊗	10.41	9.97	13.62	10.99	⊗	9.09						
Shannon's diversity index	2.80	3.07	3.11	2.49	⊗	2.74	2.75	3.01	2.67	⊗	2.70						
Log series diversity	8.87	10.16	9.84	6.57	⊗	9.36	10.23	11.24	8.92	⊗	10.13						
Evenness	0.70	0.77	0.78	0.62	⊗	0.69	0.69	0.75	0.67	⊗	0.68						
Mean minimum temperature (°C)	10.4 ± 0.91	15.6 ± 0.69	23.1 ± 0.70	12.3 ± 1.39	4.1 ± 0.76	10.6 ± 1.15	12.6 ± 0.51	17.3 ± 0.74	14.6 ± 0.59	5.8 ± 0.58	18.1 ± 1.00						
Mean maximum temperature (°C)	26.6 ± 1.04	31.5 ± 1.55	38.5 ± 0.86	25.7 ± 1.77	21.6 ± 0.84	26.1 ± 1.43	24.8 ± 0.98	32.0 ± 1.19	27.3 ± 0.88	19.9 ± 0.50	31.0 ± 1.83						
Mean rainfall (mm)	0	0	0.4 ± 0.28	0	0	0.4 ± 0.39	0.3 ± 0.00	0.9 ± 0.85	0.1 ± 0.00	0	1.9 ± 1.20						
Mean cloud cover (oktas)	2.5 ± 0.60	2.4 ± 0.61	4.3 ± 0.52	4.2 ± 1.00	1.3 ± 0.67	3.8 ± 0.73	5.2 ± 0.58	3.5 ± 0.55	3.3 ± 0.72	1.8 ± 0.50	3.9 ± 0.79						

⊗ species and abundances are too low to estimate values, # = number, for weather variables means ± 1 se are shown
* no hatchlings were caught during this survey period, numbers in parentheses indicate percentage of hatchlings caught during that survey period for that taxonomic group

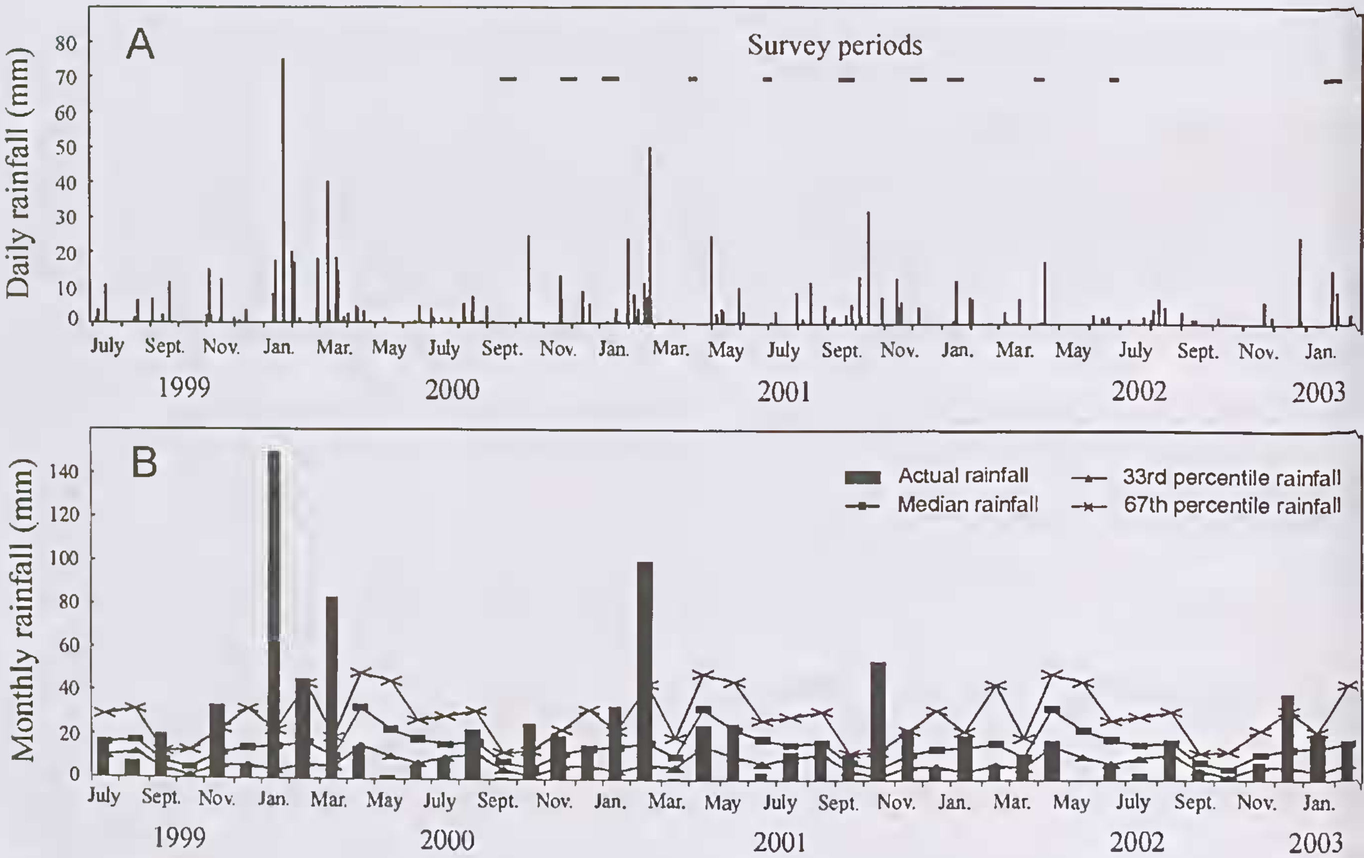

Figure 3. Daily rainfall from July 1999 until February 2003 taken at Placer Dome Asia Pacific, Kalgoorlie West Operations with days in which pit-traps were open indicated (horizontal bars; A) and monthly rainfall, median rainfall, 33rd and 67th percentiles (B) based on data taken from the Bureau of Meteorology in Kalgoorlie from 1939 to 2001.

from thunderstorms or decaying tropical depressions that can precipitate large quantities of rain over a couple of days (Fig 3A). Two decaying tropical depressions produced a significant amount of rain in January (103 mm) and March (40 mm) 2000, and a heavy localised thunderstorm in February 2001 produced 63 mm of rainfall (Fig 3A; n.b. rainfall for 2 successive days have been added to obtain these totals). Total rainfall for January to March in 2000 was 278 mm, for January to March in 2001 it was 134 mm, and for January to March in 2002 it was 38 mm. Summer rainfall greater than 40 mm in a 24 hour period was apparent in 1988, 1992, 1993, 1994, 1995, 1999, 2000 and 2001.

Heavy rains in January and March 2000 (Fig 3A) resulting from decaying tropical depressions caused some of the annuals to sprout and flower, and some of the perennials to flower in the months that follow (pers. obs.). There was one day in October 2000 where 24.5 mm of rain was recorded and this took the monthly average above the 67th percentile (Fig 3B). This rain fell between the September and December 2000 survey periods. Heavy rain recorded in January and February 2001 was between the January and April 2001 survey periods. There was 0.75 mm of rain in March and no rain until 19 April 2001. Because there was no 'follow-up' rains most of the annuals that sprouted died and the heavy January/February rains did not translate into substantial vegetation regrowth. Similarly, the 32 mm of rain on 14 October 2001 had 7 mm of 'follow-up' rain on 29 October and another 12 mm on 15 November. These follow-up rains were insufficient to sustain most of the annuals that sprouted after the 14 October rains. Thirty nine mm of rain over three days (25–27) in December 2002 had follow-up rains of 21 mm on 27–28 January 2003.

Mean minimum and maximum ambient daily temperature and cloud cover are reported for the Kalgoorlie-Boulder Airport and rainfall for Kalgoorlie West Operations in Table 2 for each survey period. Mean minimum and maximum daily temperatures in December and January of 2000/01 were significantly higher (t_{26} =3.40, $P < 0.001$ min. t_{26} = 3.66, $P < 0.01$ max. Dec.; t_{26} = 5.65 $P < 0.001$ min, t_{26} = 4.43, $P < 0.001$, max. Jan.) than for the same survey periods in 2001/02. Mean minimum or maximum ambient daily temperatures for September 2000 or April of 2001 did not differ significantly from those in the same periods in the subsequent years.

Reptiles

We caught 2868 individuals from 51 reptile species across nine sites during eleven survey periods (Table 2). Catch numbers and measured species richness were appreciably lower in June for both years (2001, 5 and 2002, 2). Measured species richness and the total number of individuals caught were highest of all survey periods in January for both 2001 (566 individuals, 40 species) and 2002 (383 individuals and 40 species; Table 2). Spring (September) surveying yielded a significantly higher

Table 3

Similarity (Morisita-Horn similarity index) among survey periods (excluding June)

	Sep-00	Dec-00	Jan-01	Apr-01	Sep-01	Dec-01	Jan-02	Apr-02
Dec-00	0.81							
Jan-01	0.75	0.91						
Apr-01	0.75	0.75	0.77					
Sep-01	0.92	0.83	0.78	0.83				
Dec-01	0.91	0.84	0.80	0.84	0.95			
Jan-02	0.85	0.92	0.91	0.80	0.92	0.90		
Apr-02	0.84	0.84	0.83	0.84	0.89	0.87	0.91	
Jan-03	0.71	0.82	0.82	0.90	0.85	0.84	0.87	0.87

number of individuals and species than autumn (April) for both years (402 vs 154 individuals, 34 vs 21 species in 2000/01, 221 vs 138 individuals, 30 vs 25 species in 2001/02). More reptiles were caught in the first 12 months of surveying than in the second 12 months (September to April 2000/01 1591 vs 967 in 2001/02).

As might be expected, various measures of species diversity were highest when catch rates and species richness were highest (Table 2). Similarity scores greater than 0.9 demonstrated high similarity in species richness and abundance for January 2002 with December 2000 (0.92) and 2001 (0.90), January 2001 (0.91) and September 2001 (0.92; Table 3). Noticeably lower similarity scores (i.e. < 0.80) were recorded for April 2001 with September 2000 (0.75), December 2000 (0.75) and January 2001 (0.77); catches in September 2001 were comparatively dissimilar to January 2001 (0.78); and September 2000 differed appreciably from January 2003 (0.71).

We caught seven species of agamids. The two most abundant were *Pogona minor* (56 captures) and *Ctenophorus reticulatus* (50 captures) and these were mostly caught in September and January surveying periods (Table 2). Gravid *P. minor* were often seen on gravel roads around Ora Banda during September in both surveying years. Increased capture rates for these two species in January reflected the number of hatchlings caught. Although the numbers of other agamids (*Ctenophorus scutulatus, Tympanocryptis cephala, Ctenophorus cristatus* and *Caimanops amphiboluroides*) caught were low, the catch pattern was similar to that for *P. minor* and *C. reticulatus*, except for *Moloch horridus*. *Moloch horridus* captures did not appear to conform to any particular pattern of activity other than they were not caught in June (Table 2).

We caught 10 species of geckos. The most abundant geckos were *Diplodactylus granariensis* (346), *D. maini* (401) and *D. pulcher* (432). The abundance pattern for geckos appeared to be closely linked with ambient temperature. Catch rates for January (334 for 2001 and 224 for 2002) were higher than for December (267 for 2000 and 156 for 2001), which in turn were higher than for September (221 for 2000 and 141 for 2001) for both years. The number of geckos caught in April (107 for 2001 and 84 for 2002) was less than that caught in September, December and January.

Seventeen species of skinks were caught. Two of these belong to the genus *Tiliqua*, which because of their size, were not often caught in pit-traps but were occasionally seen on gravel roads, particularly in September. Of the smaller and more easily pit-trapped skink species, the most abundant were the terrestrial foraging *Ctenotus uber* (107) and *C. atlas* (70), arboreal *Egernia depressa* (90), fossorial *Lerista picturata* (89) and the very small terrestrial litter dwelling *Menetia greyii* (93). The pattern of captures for small skinks was similar to that for geckos, with January (151 in 2001 and 85 in 2002) captures being higher than for December (140 in 2000 and 43 in 2001), which in turn was higher than for September (118 in 2000 and 39 in 2001), which was higher than for April (39 in 2001 and 33 in 2002). The number of skinks caught in the second summer (200) was appreciably less than caught during the same period in 2000/01 (448). The skink species most noticeably different to this pattern was *Menetia greyii*. More than a third (37/93) of all captures for *M. greyii* were caught in September 2000, the next highest number of individuals caught was April 2001 (15), followed by January 2001 (12) and December 2000 (8; Table 2). For the second summer, catch rates for this species were low for each of the four surveying periods in the warmer months (Table 2).

We caught three species of blind snakes; *Ramphotyphlops australis* (39), *R. hamatus* (60) and *R. bituberculatus* (3). Catch rates for the two most abundant species provided a consistent pattern across the two years, with comparatively higher numbers being caught in September and January and lower numbers in December and less in April (Table 2). More *R. australis* than *R. hamatus* were caught in September 2000 (12 vs 6), December 2001 (3 vs 0) and January 2003 (10 vs 3), but the reverse was the case for the other survey periods.

The number of elapids, varanids and pygopods caught was low and trends were difficult to detect (Table 2).

Hatchlings

Hatchlings were most frequently pit-trapped in January and April. For summer 2000/01, the proportion (number of hatchlings for each taxonomic group / total number of individuals for each taxonomic group) of hatchlings caught in January (8.5%) and April (7.8%) was similar, although more hatchlings were caught in January (48) than April (12; Table 2). However, in the summer of 2001/02 there was a higher proportion of hatchlings caught in April (10.9%) than January (3.9%), and the overall number of hatchlings caught in January 2002 (15) was less than in 2001 (48). Hatchling agamids were plentiful in January 2001 (16), less abundant in January 2002 (7) and none were caught in January 2003

(Table 2). Hatchling geckos were most abundant during January 2001 (16) with low numbers being caught during the other two January survey periods (3 in both 2002 and 2003). Hatchling skinks were caught in similar numbers for December (8), January (9) and April (7) 2000/01 survey periods, but were only caught in similar numbers again in April 2002 (8: Table 2).

Discussion

Variation on weather patterns

During our two and half year survey (September 2000 – January 2003), summer rains (with the necessary follow-up rains) that resulted in many of the annuals growing to maturity and flowering, and the perennials flowering only occurred after the heavy rains in January 2000. The effect of these rains on reptile abundance in the following spring and summer are unknown and difficult to quantify without data for the same period in previous years. Heavy summer rain may damage reptile eggs buried in the ground reducing recruitment, as many of the hatchlings were first detected in January. These rains may have increased survivorship of those individuals that hatched because of the additional food supply (Haynes 1996). The number of reptiles caught in the spring-summer of 2000/01 was greater than for the following spring-summer, which may have been a consequence of the heavy January 2000 rainfall. There were three other significant rainfall events (February 2001, October 2001 and December 2003) within the two and one half year survey period that potentially could have affected reptile abundance. Heavy rainfall in February and October 2001 had insufficient 'follow-up' rain to result in an appreciable change in the vegetation and therefore prey abundance (Dunham 1978; Dickman *et al.* 1999). The December 2002 rainfall was too close to our survey period in January 2003 to have an affect on the number of individuals caught.

Potential impact of rainfall on reptile abundance

Terrestrial reptile reproductive output (clutch size, number of clutches and survivorship) and growth are influenced by preceding rainfall for many arid and semi-arid reptiles (Nagy 1973; Bradshaw *et al.* 1991; James 1991; Castilla *et al.* 1992; Saint Girons *et al.* 1992; Tinkle *et al.* 1993; Spiller & Schoener 1995; Dickman *et al.* 1999), although Whitford & Creusere (1977) reported that there was no correlation between summer rainfall (June-July) and changes in reptile density in the Chihuahuan Desert. If heavy rainfall was to have an affect, then when rainfall exceeded the 67th percentile it should be followed by some change in relative catch abundance of reptiles. Rainfall exceeded the 67th percentile for the months of January, February and March 2000 and the effects should have been evident in the following autumn and perhaps the subsequent spring surveys. Heavy rains were again recorded in January and February 2001, which should have affected reptile abundance in the following autumn, and the spring survey, if the affect carried over the winter months. If rainfall generally increased reptile abundance, then the above 67th percentile rains that were recorded in October 2001 should have recorded an affect for the surveys during December 2001, and January and April 2002, and above the higher than 67th percentile rains in December 2002 may have had an affect on reptile abundances for the January 2003 survey (if it was not too soon). There is insufficient chronosequenced captures to examine species-specific data statistically, but an examination of overall catch rates shows no systematic changes in reptile numbers overall, or for any of the families (Table 2), following these above the 67th percentile months of rainfall. The overall pattern of change between years and seasons, therefore does not appear to have been noticeably affected by heavy rainfall events. However, as pointed out by Dickman *et al.* (1999), it is possible for one species in a family to increase in abundance and a sister species to decrease in abundance in response to rain and for one affect to mask the other.

Seasonal variation

Ectothermic reptiles were not expected to be active during the month of June around Ora Banda, and pit-trap captures reflected daily ambient temperatures that were too low to enable most reptile species to be surface active, and thus caught in pit-traps. Obviously, terrestrial fauna surveys undertaken during the cooler months are unlikely to provide an adequate indication of herpetofauna in the area. Although this seems obvious, environmental consultants continue to undertake terrestrial fauna surveys in the cooler months for the purposes of recording the fauna (including reptiles) in areas that are likely to be disturbed by a potential development. Inappropriate or a lack of guidance from the appropriate government environmental protection authorities may, in part, be responsible for this.

We recorded 51 pit-trappable species of reptiles in the Ora Banda area, however, the highest number of species caught during the 3024 pit-trapping days for any of the eleven survey periods was only 40 species during January 2001 and 2002. Similarity scores indicated that active, and available to be caught reptile assemblages, varied significantly among seasons (Table 3). Taken together, these two results suggested that our trapping effort during each survey was insufficient to catch all the species that could be caught in the area during any survey period (also see Thompson *et al.* 2003) and that pit-trapping must be undertaken in more than one season to obtain an accurate appreciation of the reptile assemblage in the Goldfields region of WA, a view expressed by Fraser *et al.* (2003) and Cowan & How (2004). The EPA (2004) indicated that surveys conducted for baseline information (i.e. the first survey of the area prior to development) should be undertaken in multiple seasons (pp. 12), however, few EIAs are based on multiple surveys as suggested by this guidance statement. Our data indicate that pit-trapping fauna surveys in January provided the highest number of individual captures (individuals per 10 pit-trap nights: September 1.33 and 0.73, December 1.53 and 0.74, January 1.87, 1.27 and 1.03, and April 0.51 and 0.46) and highest measured species richness (September 34 and 30, December 39 and 32, January 40, 40 and 35, and April 21 and 25). Similarity scores for January and September (0.75, 0.85, 0.71, 0.78, 0.92, 0.85) or January and April (0.77, 0.83, 0.80, 0.90, 0.91, 0.87) were often less than 0.90, indicating that the species caught and their relative abundance varied between these two survey periods. Similarity scores between January and December (0.91, 0.92, 0.82, 0.80, 0.90, 0.84) were generally the highest

(Table 3), as might be expected due to the closeness of these two survey periods and the similarity in weather conditions. January data include more hatchlings than the December data and for some species only hatchlings were caught (e.g. *Ctenophorus cristatus*). Some of the larger varanids (e.g. *Varanus gouldii*) and adult large agamid lizards (e.g. *Ctenophorus cristatus*) are difficult to pit-trap in either 20 L PVC buckets or 150 mm PVC pipes (600 mm deep) as they can easily jump over 150 mm diameter pipes and jump out of 20 L buckets. More individuals were caught in spring than in autumn, increasing the probability of more species being caught in spring. As the difference in similarity scores is slightly greater between January and September, than January and April, these data suggested that where two surveys are to be undertaken they should occur in September and January to provide a better appreciation of the reptile assemblage. These findings are different to those of How (1998) who reported that a fauna survey in November and December on the mesic Swan Coastal plain of WA yielded appreciably higher catches (4.35 and 5.03 individuals per 10 pit-trap nights respectively) than either spring (1.36 for September and 1.32 for October), autumn (April 1.72), January (2.68) or February (1.78).

James (1994) suggested that it was difficult to disentangle reptile assemblage responses to seasonal changes in temperature from responses to changes in rainfall. James (1994) compared variation in lizard assemblages in each spring and autumn over a two year period (spring 1985 to spring 1987) for a 50 ha spinifex grassland on a dune-swale system south of Alice Springs in central Australia. He reported little rainfall in the first season, however, the second season (November 1986–March 1987) was affected by unusually heavy winter (June and July) rains, and the third season was dry. He concluded that the changes in hydric conditions profoundly influenced lizard population dynamics and reproductive activity, although he was unable to factor out 'natural' year-to-year variation in lizard assemblages for the area when conditions were within the 'normal' range. Similar to our results, James (1994) reported some species were more abundant in spring than autumn (e.g. *Ctenophorus isolepis, Diplodactylus conspicillatus*), while other species were more abundant during autumn than spring (e.g. *Rhynchoedura ornata*). Masters (1996) reported significant seasonal variation in both total abundance and number of reptile species caught during her surveys (sites burnt in 1976) of spinifex dominated sandplains with scattered shrubs west of Ayers Rock. May and August surveys generally had lower numbers of both individuals and species, similar to our results for cooler conditions.

Our data indicate that if resources are available, a comprehensive terrestrial fauna surveys (150 individuals caught using a combination of 20 L PVC buckets, 150 mm PVC pipes and funnels traps joined by drift-fences for each habitat type; authors unpub. data) should be undertaken in late spring (September – October), January and autumn (March–April) to provide the best understanding of reptile assemblages in the goldfields. If resources are limited, our data indicate the surveying effort is best applied in two periods; late spring (September–October) and January, rather than spreading the surveying effort (and resources) over three periods. Inadequate survey effort to assess species richness for the purpose of preparing an EIA is a serious problem in Australia (Benkendorff 1999). Thompson *et al.* (2003) provide a commentary on this issue and explained how species accumulation curves can be used to estimate the pit-trapping effort necessary to capture a nominated proportion of the species in an area. Cowan & How (2004) pointed out that there are appreciable variations in capture rates for reptiles between Spring and Autumn surveys and suggested one-off short-term surveys are inadequate to determine vertebrate assemblages for EIA purposes, a view we would strongly support.

Year-to-year

Year-to-year variations in reptile assemblages were appreciable between the two years surveyed (see similarity scores in Table 3). Read (1992, 2002) from his surveys of grazing and mining habitats at Olympic Dam, South Australia provided data to indicate that reptile diversity, species richness and capture rates during December varied appreciably among years (1987 to 1991; 1994 to 1997, respectively). Capture rates for the six most commonly trapped reptile species outside mined areas (*Ctenotus regius, Ctenotus schomburgkii, Diplodactylus stenodactylus, Rhynchoedura ornata, Lerista labialis* and *Ctenophorus fordi*) differed appreciably, with no common pattern evident (Read 1992). Read (2002) indicated a similar level of variation in reptile abundance for his 'control' sites when he examined the effect of grazing on reptile assemblages in chenopod shrublands. These variations were of a similar order to that which we report here for commonly caught species from the same genera [e.g. *Ctenotus atlas* (70), *Diplodactylus granariensis* (346), *D. maini* (401), *D. pulcher* (432), *Rhynchoedura ornata* (124), *Lerista muelleri* (45) and *Lerista picturata* (89)] and others [e.g. *Strophurus assimilis* (141) and *Egernia depressa* (90)]. How (1998) reported that there were appreciable variations in the reptile assemblage of Bold Park, a remnant bushland (330 ha) on the coastal plain west of Perth, among years and although he normally caught all of the common species each year, abundance of these common species varied appreciably. Interestingly, year-to-year variation in the number of individuals caught in recently burnt areas was less than for the sites burnt more than 10 years earlier in the arid interior of Australia (Masters 1996). Masters (1996) reported appreciable variation in the number of species caught between years for the same season in long burnt sites. Dodd (1992) also reported considerable annual variation in the reptile community around a temporary pond situated in the Florida sandhills, and as the drought progressed the rarer species disappeared and the abundance of other species declined. Cowan & How (2004), in comparing reptiles trapped in March 1979, October 1980, October 2001 and March 2002 at Goongarrie Station, showed that the October 2001 and March 2002 assemblages were the most similar, and more similar to the March 1979 than the October 1980 assemblages.

Overall captures were less in the warmer months of 2001/02 than 2000/01 around Ora Banda, and this was most noticeable for geckos and skinks (Table 2). Mean minimum and maximum daily ambient temperatures were significantly warmer in December and January of 2000/01 than 2001/02 survey period. This might have accounted for the lower number of geckos and skinks caught in 2001/02. However, the mean minimum and maximum daily ambient temperatures for September 2000 and 2001 were not significantly different but the number of geckos and skinks caught in 2000 was appreciably higher than 2001. This led us to conclude that factors other than ambient temperature, which we could not identify, could have also contributed to the year-to-year variation in catch rates. Interestingly, Brown & Shine (2002) reported considerable daily variation in activity levels for snakes in tropical Australia, but concluded that standard weather variables such as temperature, humidity and precipitation were poor predictors of activity.

It rained for a number of days during the second week of pit-trapping in January 2003 (total of 32.5 mm). It also rained in January 2001 (total of 6 mm) and 2002 (total of 12.15 mm), but not as heavily (Table 2). We believe the total number of individuals and species caught were less in January 2003 than in the two previous January surveys because reptiles were generally less active in the cooler days associated with the higher rain (Table 2). However, this rain may have caused the increased catch rates for a couple of species. The proportional number of termite eating specialist geckos (*D. pulcher*, *R. ornata*) was higher in January 2003 than in previous January surveys. The abundance of termites and possibly other invertebrates immediately after the rain may have made feeding relatively easy. We observed many swarms of termites active on the surface of logs and the leaf litter mid-morning on the first day after heavy rain. Most *D. pulcher* and *R. ornata* pit-trapped immediately after the heavy rain had engorged themselves and had distended abdomens from feeding on termites. These data suggest that these two termite specialist feeding geckos that can forage at lower body temperatures (Roberts 1998) were taking advantage of the available food resource, and were being caught in our pit-traps in higher numbers as a consequence. In contrast, catch rates for the diurnal, termite eating specialist skink *Egernia depressa*, and *Ctenotus uber* and *Ctenotus atlas* whose diets are also predominantly termites, were not higher after rain. The cooler ambient day temperature during the 3–4 days after rain possibly limited foraging opportunities for these skink species.

Can we misinterpret natural year-to-year variation as being caused by some stochastic event? Pianka (1996) compared lizard assemblages on the western edge of the Great Victoria Desert (L-area) for three periods (1966–68, 1978–79, 1989–92) and attributed changes in species richness and abundance between these periods to fires in 1968–69 and 1983. Fires probably were a major contributor to these changes, but in the absence of an understanding of 'normal' year-to-year variation, it is difficult to attribute all differences to fires. In addition, variations in the total number of captures (530 in 1966–68; 1565 in 1978–79; 1997 in 1989–92) would have also influenced estimates of species richness and abundance (Gotelli & Graves 1996, Thompson *et al.* 2003) as may have been the removal of all caught individuals from the study site during each sampling. Pianka (1996) also reported species diversity increased at another of his study sites (Redsands) between 1978–79 and 1989–92 and again suggested a fire in 1982 was a significant contributor to this increased diversity. The latter survey was more comprehensive (1436 individuals vs 3196 individuals) as a consequence of a higher surveying effort. Variations in catch rates for some species between the two successive years at our Ora Banda study site exceeded those reported by Pianka where there are 10 years between survey periods. We are not suggesting that the fire had no impact on diversity or abundance at Redsands or L-area, as it clearly did, as much of the spinifex was destroyed and many of the small reptiles use spinifex as shelter and their primary foraging site in the Great Victoria Desert (Pianka 1986).

Masters (1996) in a study of the impact of fire on reptile abundance and species richness in Uluru National Park reported that relative abundance of reptile fauna on regenerating (from fire) plots changed over three years. During the third year of her investigation, Masters reported total abundance for the February survey period (1990) in the area burnt 12 years earlier declined significantly compared with the previous two years (1988 and 89), whereas a similar change was not evident in the area burnt some 2–4 years earlier. For species richness, the February survey in the third year (1990) was comparable with the first year (1988), but the number of species caught in the second year (1989) for the areas burnt 2–4 and 10–12 years earlier was higher. Masters (1996) suggested that as the total (vegetation) cover increased in recently burnt areas the number of diurnal species caught increased (although data supporting this claim were not provided). What is evident from Masters (1996) data is that there were considerable year-to-year variations in both total abundance and species richness for long burnt sites (controls). We know that abundance of captures is positively correlated with the number of species caught in arid and semi-arid habitats in Australia (Thompson *et al.* 2003), and the comparatively low number of individuals caught in the third year of Masters' surveying may have influenced the reported species richness values for that year or there may have been a real decline in reptile abundance. Therefore, some of the difference in species richness attributed to succession or vegetation cover was probably 'normal' year-to-year variation and a result of inadequate surveying.

Conclusion

A terrestrial faunal survey undertaken for the purposes of preparing an EIA can only describe the assemblage for a particular period in time. As activity patterns for reptiles and capture rates vary seasonally, terrestrial faunal surveys need to be undertaken in more than one season. In the Goldfields region of WA, surveys should ideally be conducted in spring, summer and autumn; and if this is not feasible then the surveys should be undertaken in September/October and January. Data from terrestrial fauna surveys can also be used to monitor rehabilitation success and impacts of disturbance on adjacent areas. This recommendation has obvious significant financial consequences for mining companies and other agencies that want to disturb the natural environment and arrange to have terrestrial faunal surveys undertaken to describe the faunal assemblage in the area to prepare an EIA. Similarly, government agencies undertaking faunal surveys of particular areas or regions for the purpose of zoning land for reserves or recording the biodiversity need to survey in more than one or even two seasons, and need to understand that assemblages can change appreciably from year-to-year. We concur with the views of How (1998 pp. 148) who argued that 'an extensive sampling effort was required in both temporal and spatial scales before the composition of a herpetofaunal assemblage can be adequately determined'. This view is also supported by more recent data presented by Cowan & How (2004) for the Goldfields.

In most circumstances, the current level of knowledge cannot separate natural year-to-year variation in reptile assemblages from variations attributable to stochastic events such as fire, grazing, drought or unseasonally heavy rainfall. Long-term studies of variations in reptile assemblages are therefore required if we are to adequately interpret the impact that stochastic events have on particular areas. The extent of year-to-year variations in reptile assemblages will differ in accordance with climate, vegetation and topography. Such studies are therefore required in a range of habitats. Ideally, a Before-After-Control-Impact (BACI) experiment with appropriate replication is necessary to demonstrate the impact of stochastic events and how they differ from natural seasonal and year-to-year variations. Investigations such as those cited above that link temporal variations to fire or unusual rainfall events lack both adequate replication and 'before' data. However, it is not always possible to establish such experiments and alternative research designs are necessary. Underwood (1994) suggested a way around the problem of a lack of adequate 'before' data. Because natural variations recur repeatedly it may be possible to sample a range of randomly chosen replicates in undisturbed habitats to establish natural variance among times, locations and their interactions. These data could then be used for comparison with data collected 'after' at control sites and given no difference, then used as 'before' data to compare with the 'impact' data.

Acknowledgements: This research was undertaken with ethics approval granted by Edith Cowan University and licences issued by the Department of Conservation and Land Management. This research was financially supported by OMG Cawse Nickel and Placer Dome Asia Pacific, Kalgoorlie West Operations for which we are very appreciative. Comments by E. R. Pianka and reviewers were most appreciated.

References

Benkendorff K 1999 The need for more stringent requirements in environmental impact assessment: Shell Cove marina case study. Pacific Conservation Biology 5: 214–223.

Bradshaw S D, Saint Girons H & Bradshaw F J 1991 Patterns of breeding in two species of agamid lizards in the arid subtropical Pilbara region of Western Australia. General Comparative Endocrinlogy 82: 47–424.

Brown G P & Shine R 2002 Influence of weather conditions on activity of tropical snakes. Austral Ecology 27: 596–605.

Castilla A M, Barbadillo LJ & Bauwens D 1992 Annual variation in reproductive traits in the lizard *Acanthodactylus erythrurus*. Canadian Journal of Biology 70: 395–402.

Cogger H G 1992 Reptiles and Amphibians of Australia. Reed, Sydney.

Colwell R K 1997 EstimateS: Statistical estimation of species richness and shared species samples. (Version 6.01). Available: http://viceroy.eeb.uconn.edu/estimates.

Cowan M A & How R A 2004 Comparisons of ground vertebrate assemblages in arid Western Australia in different seasons and decades. Records of the Western Australian Museum 22: 91–100.

Dickman C R, Letnic M & Mahon P S 1999 Population dynamics of two species of dragon lizards in arid Australia: the effects of rainfall. Oecologia 119: 357–366.

Dodd C K 1992 Biological diversity of a temporary pond herpetofauna in north Florida sandhills. Biodiversity and Conservation 1: 125–142.

Dunham A E 1978 Food availability as a proximate factor influencing individual growth rates in iguanid lizard *Sceloporus merriami*. Ecology 59: 770–778.

Environmental Protection Authority 2002 Terrestrial Biological Surveys as an Element of Biodiversity Protection. Environmental Protection Authority, Perth, Western Australia.

Environmental Protection Authority 2004 Terrestrial fauna surveys for environmental impact assessment in Western Australia: No 56, June 2004. Environmental Protection Authority, Perth, Western Australia.

Fraser J L, Thompson G G & Moro D 2003 Adequacy of terrestrial fauna surveys for the preparation of Environmental Impact Assessments in the mining industry of Western Australia. Ecological Management and Restoration 4: 189–192.

Gotelli N J & Graves G R 1996 Null Models in Ecology. Smithsonian Institution Press, Washington.

Haynes R S 1996 Resource partitioning and demography of twelve sympatric skinks (*Ctenotus*) in the Simpson Desert. Unpublished Honours thesis, University of Sydney.

How R A 1998 Long-term sampling of a herpetofaunal assemblage on a isolated urban bushland remnant, Bold Park, Perth. Journal of the Royal Society of Western Australia 81: 143–148.

James C & Shine R 1985 The seasonal timing of reproduction. Oecologia 67: 464–474.

James C D 1991 Annual variation in reproductive cycles of scincid lizards (*Ctenotus*) in central Australia. Copeia 1991: 744–760.

James C D 1994 Chapter 13, Spatial and temporal variation in structure of a diverse lizard assemblage in arid Australia. In: Lizard Ecology (eds L J Vitt & E R Pianka) Princeton University Press, New Jersey, 287–317.

Magurran A E 1988 Ecological Diversity and Its Measurement. Princeton. Princeton University Press, New Jersey.

Masters P 1996 The effects of fire-driven succession on reptiles in spinifex grasslands at Uluru National Park, Northern Territory. Wildlife Research 23: 39–48.

Mattiske Consulting Pty Ltd. 1995 Flora and vegetation of the Cawse find area. Perth. Unpublished report: Mattiske Consulting Pty Ltd, Perth.

Nagy K A 1973 Behavior, diet and reproduction in a desert lizard, *Sauromalus obesus*. Copeia 1973: 93–102.

Pianka E R 1986 Ecology and natural history of desert lizards: Analyses of the ecological niche and community structure. Princeton University Press, Princeton.

Pianka E R 1996 Long-term changes in lizard assemblages in the Great Victoria Desert: Dynamic habitat mosaics in response to wildfires. In: Long-term Studies of Vertebrate Communities (eds M J Cody & J A Smallwood) Academic Press, San Diego, 191–215.

Pisces Conservation Ltd 2002 Species diversity and richness II (Version 2.6), Pisces Conservation Ltd: England.

Read J 1992 Influence of habitats, climate, grazing and mining on terrestrial vertebrates at Olympic Dam, South Australia. Rangeland Journal 14: 143–156.

Read J L 2002 Experimental trial of Australian arid zone reptiles as early indicators of overgrazing by cattle. Austral Ecology 27: 55–66.

Roberts A R 1998 Ecophysiology of semi-arid geckos. Relationships between ecology and physiology in sympatric nocturnal geckos from a semi-arid sandplain habitat with particular emphasis on locomotion and thermal biology. Unpublished PhD thesis, The University of Western Australia, Perth.

Saint Girons H, Bradshaw S D & Bradshaw F J 1992 The reproductive cycles of a number of species of lizards from southern and north-western regions of Western Australia. Journal of the Royal Society of Western Australia 75: 57–64.

Spiller D A & Schoener T W 1995 Long-term variation in the effect of lizards on spider density is linked to rainfall. Oecologia 103: 133–139.

Thompson A S 2004 Mine site rehabilitation index using reptile assemblage as a bio-indicator. Unpublished PhD thesis, Edith Cowan University, Perth.

Thompson G G, Withers P C, Pianka E R & Thompson S A 2003 Assessing biodiversity with species accumulation curves; inventories of small reptiles by pit-trapping in Western Australia. Austral Ecology 28: 361–383.

Tinkle D W, Dunham A E & Congdon J D 1993 Life history and demographic variation in the lizard *Sceloporus graciousus*: A long-term study. Ecology 74: 2413–2429.

Tramer E J 1969 Bird species diversity, components of Shannon's formula. Ecology 50: 927–929.

Underwood A J 1994 On beyond BACI: sampling designs that might reliably detect environmental disturbances. Ecological Applications 4: 3–15.

Whitford W G & Creusere F M 1977 Seasonal and yearly fluctuations in Chihuahuan Desert lizard communities. Herpetologica 33: 54–65